# Improving Hydrologic Predictions of Distributed Watershed Model via Uncertainty Quantification of Evapotranspiration Methods

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## ABSTRACT

Successful initialization and accurate estimation of evapotranspiration (ET) in the coastal plain landscapes are crucial for the prediction of hydrologic variables including streamflow, surficial aquifer lost and infiltration. The aim of this study is to examine the ability of Soil and Water Assessment Tool (SWAT) to accurately represent the characterization of three potential ET methods (Priestley-Taylor (P-T), Penman–Monteith (P-M) and Hargreaves (HG)) using the Sequential Uncertainty FItting (SUFI-2) algorithm during 2003-2005 and 2006-2007 as calibration and validation intervals. The study area was the Waccamaw River watershed, a low-gradient coastal plain watershed in the southeastern US. The results indicated that in estimating ET for a coastal plain landscape, P-T method bracketed more than 75% of daily streamflow during calibration period while both P-M and HG bracketed 57% and 69% of measured streamflow during calibration period, respectively. Model daily performance using P-T method was "very good" (calibration NSE = 0.77; validation NSE=0.90) but only "satisfactory" (P-M calibration NSE = 0.55; HG calibration NSE = 0.61) to "good" (P-M validation NSE=0.75; HG validation NSE=0.70) in P-M and HG methods. The prediction mean square error (MSE) for P-T method was comparably low (57.88 and 325.68) compared to P-M (68.34 and 635.95) and HG (69.99 and 551.99) methods at upstream and downstream outlets, respectively. This result suggests that radiation based ET method performed significant results in forested wetland dominated ecosystem with wet and humid surfaces. Based on the water balance analysis, only about 21.2% of flow loss was consumed via stream evaporation and floodplains evapotranspiration, indicating that 78.8% of the loss within the entire study area represented land ET and shallow aquifer recharge. Furthermore, uncertainty quantification revealed that low flows are sensitive to the changes in ET process in dry period and at the beginning of the wet season, but insensitive at the end of the wet season due to nonlinear control of coastal plain soil on water movement. In particular, under conditions of so-called "deep uncertainty" in the coastal plain landscapes, uncertainty quantification of ET methods can lead to the identification of optimal land and water management strategies in the southeastern ecosystems.

## STUDY AREA

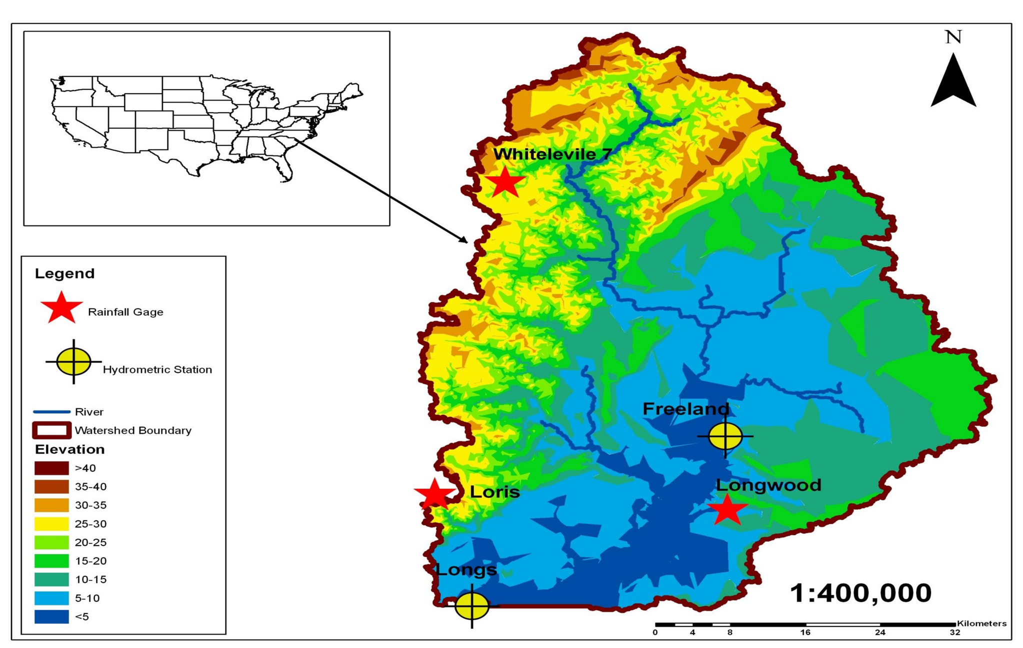


Figure 1. Location map of the study area. The delineated Waccamaw River watershed used in SWAT was 311,685 ha.

## ET PROCESS IN THE COASTAL PLAIN ECOSYSTEM

The coastal plain surface condition is characterized by several features: the meteorological conditions in which the evaporation is taking place, degree of soil saturation, solar energy, vegetation and its seasonal dynamics and the number of riparian buffers. Since the coastal plain surface is almost saturated in winter and semi-saturated or dry in summer, the rate of evaporation/evapotranspiration differs through a year (Figure 2). This inconsistent characteristics can lead to a high degree of uncertainty in hydrology model.

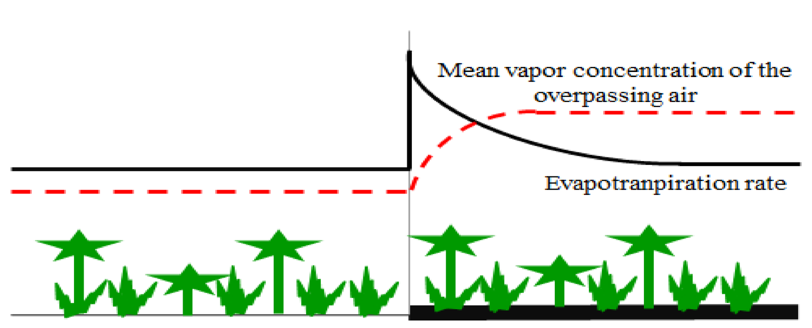


Figure 2. A Conceptual representation of evapotranspiration rate

## SWAT EVAPOTRANSPIRATION METHODS

Three methods are provided in SWAT for estimating potential evapotranspiration: Priestly-Taylor (Priestly and Taylor, 1972), Penman-Monteith (Monteith, 1965), and Hargreaves (Hargreaves and Samani, 1982). The Penman-Monteith (P-M) method requires solar radiation, air temperature, relative humidity and wind speed; Priestley-Taylor (P-T) method requires solar radiation, air temperature and relative humidity; whereas Hargreaves (HG) method requires only air temperature.

**The Penman-Monteith method**

$$ET_o = \frac{\Delta(R_n - G) + \rho_a c_p (\delta_e) g_a}{(\Delta + \gamma(1 + g_a / g_s)) L_\upsilon} \qquad \text{Equation 1}$$

**The Priestly-Taylor method**

$$PET = \alpha \frac{s(T_a)}{s(T_a) + \gamma}(K_n + L_n).\frac{1}{\rho_w \lambda_v} \qquad \text{Equation 2}$$

**The Hargreaves method**

$$PET = 0.0075.R_a.C_t.\partial_t^{1/2}.T_{avg.d} \qquad \text{Equation 3}$$

## MODEL SETUP

Soil and Water Assessment Tool (Arnold et al., 1993) is an appropriate hydrology model for complex watershed where there is heterogeneity in physical properties (e.g. soil parameters) and spatial variability in input data. In this study, Sequential Uncertainty Fitting algorithm (Abbaspour et al.,2007) was linked to the SWAT model. SUFI-2 as a Bayesian framework, depicts uncertainty as uniform distributions, while model output uncertainty is quantified by the 95 % prediction uncertainty (95PPU) calculated at the 2.5 % and 97.5 % levels of the cumulative distribution of output variables obtained through Latin hypercube sampling (Abbaspour et al., 2007). SUFI-2 was run for 18 parameters in four iterations with 500 simulation numbers during calibration (2003-5) and a single iteration with 500 simulation numbers in validation (2006-7) respectively.

## MODEL EVALUATION

Nash coefficient (NSE; equation 1), Mean Square Error (MSE; equation2), the P_Factor (equation 3) and R_Factor (equation 4) were used to evaluate SUFI-2 results.

$$NSE = 1 - \frac{\sum_{t=1}^{N}(O_i - S_i)^2}{\sum_{t=1}^{N}\left(O_i - \bar{O}\right)^2}[-] \qquad \text{Equation 4}$$

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(\bar{S}_i - O_i)^2 \qquad \text{Equation 5}$$

$$\bar{d} = \frac{1}{k}\sum_{t=1}^{k}(X_U - X_L)_t \qquad \text{Equation 6}$$

$$r - factor = \frac{\bar{d}}{\sigma_x} \qquad \text{Equation 7}$$

Where: Oi and Si are observed and simulated values respectively. Where dx is the average distance between the upper and lower 95PPU, $X_U$ and $X_L$ represent the upper and lower boundaries of the 95PPU, and σx is the standard deviation of the measured data. The goodness of calibration and predictive uncertainty is judged on the basis of the closeness of the p-factor to 100% and the r-factor to 1. The average thickness of the 95PPU band or the r-factor is estimated in every run and best simulation can be judge as a simulation with almost observed and modeled data located inside the 95% band.

## PRIESTLY-TAYLOR RESULT

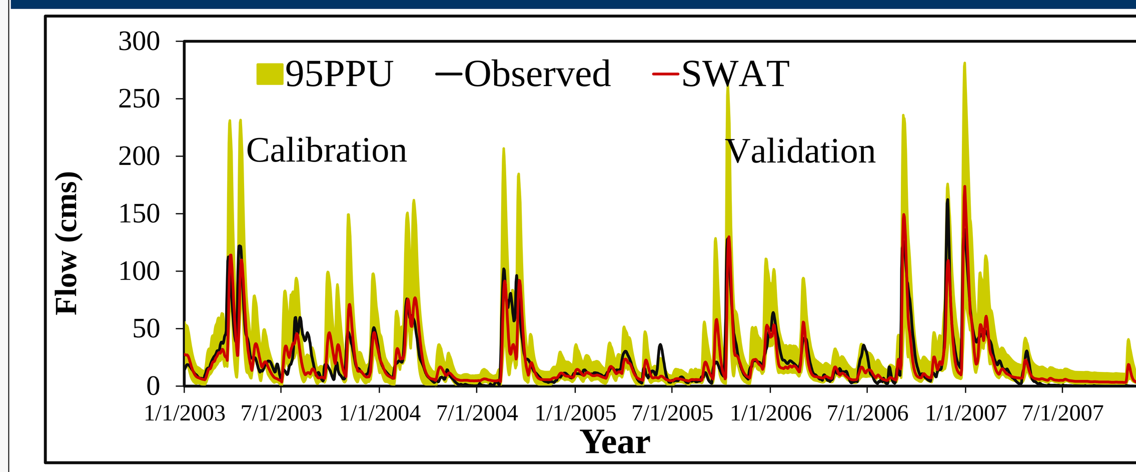


Figure 3. SUFI-2 predicted streamflow at the Freeland station.

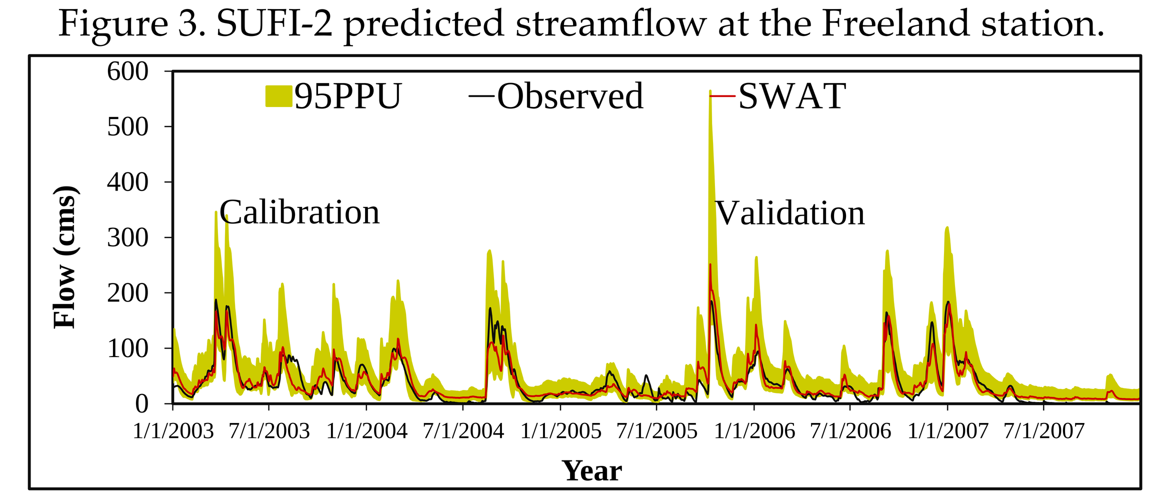


Figure 4. SUFI-2 predicted streamflow at the Longs station.

## PENMAN-MONTEITH RESULT

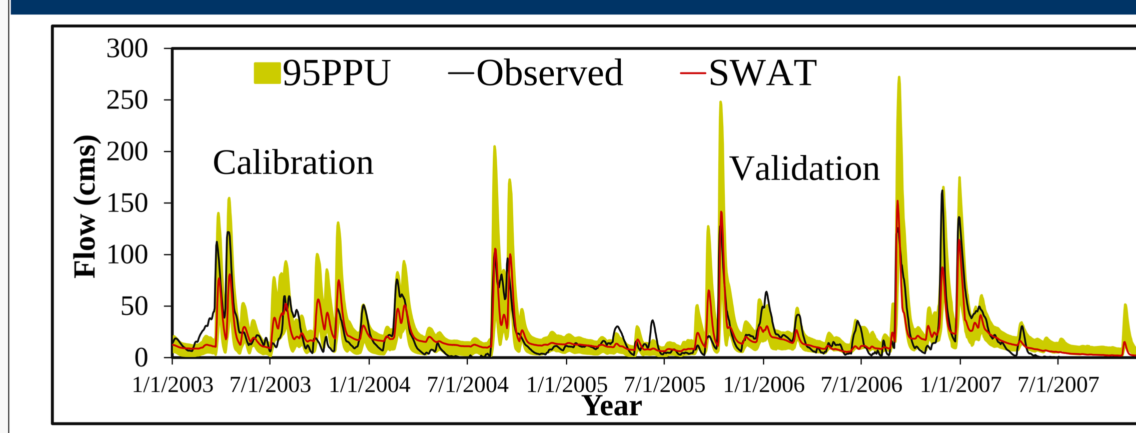


Figure 5. SUFI-2 predicted streamflow at the Freeland station.

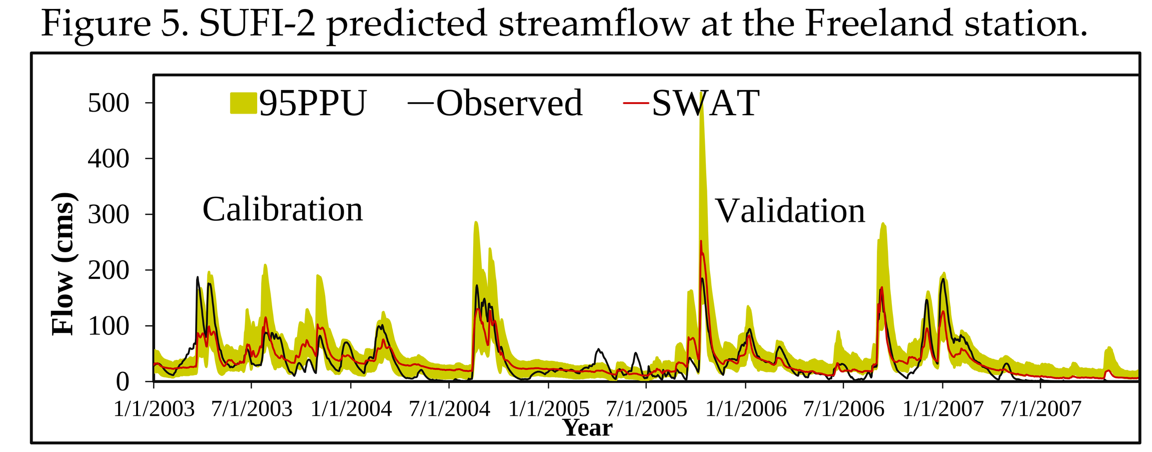


Figure 6. SUFI-2 predicted streamflow at the Longs station.

## HARGREAVES RESULT

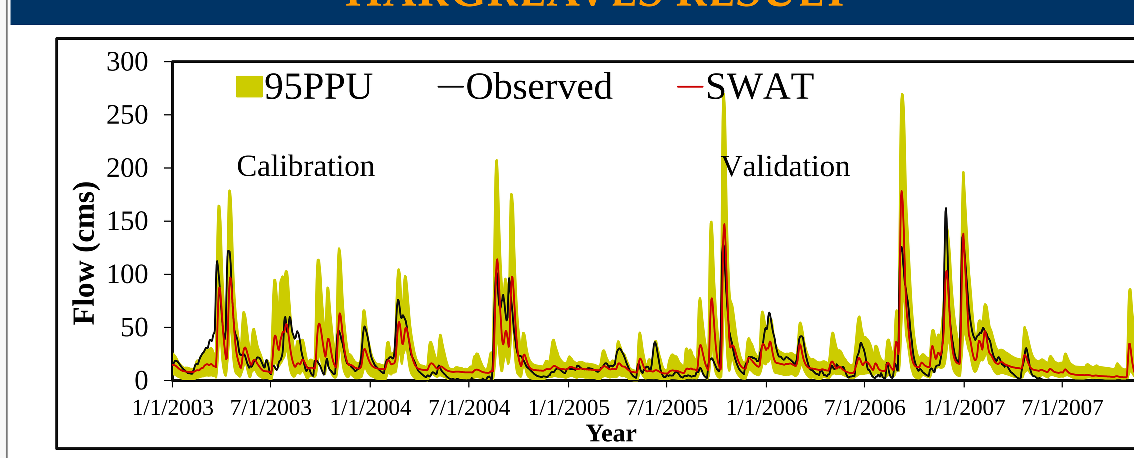


Figure 7. SUFI-2 predicted streamflow at the Freeland station

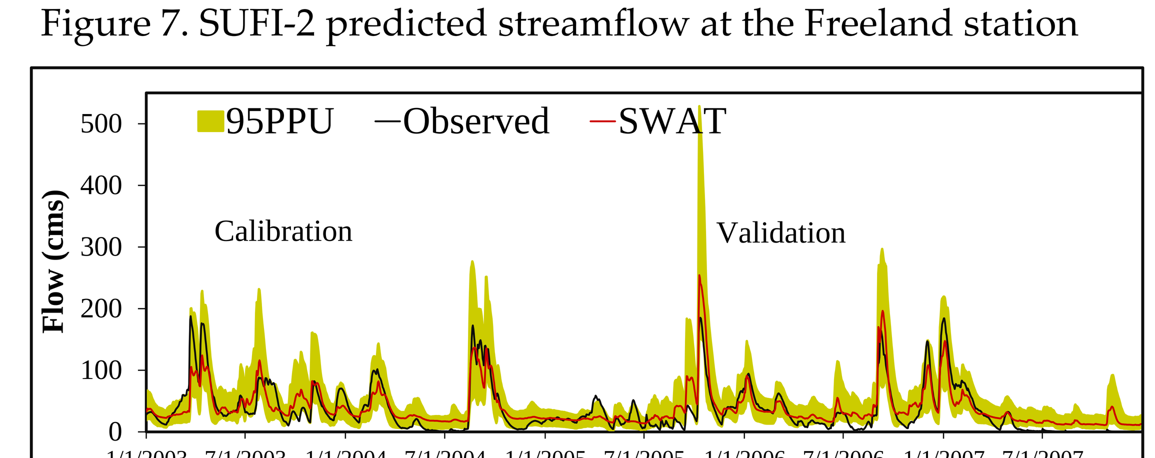


Figure 8. SUFI-2 predicted streamflow at the Longs station.

## COMPARISON OF DIFFERENT ET RESULTS

**Table 1. SUFI-2 simulation statistics for upstream (Freeland).**

| | Calibration | | | Validation | | |
|---|---|---|---|---|---|---|
| | P-T | P-M | HG | P-T | P-M | HG |
| **NSE** | 0.79 | 0.55 | 0.61 | 0.87 | 0.75 | 0.70 |
| ***MSE*** | 57.88 | 68.34 | 69.99 | 94.74 | 155.16 | 144.5 |
| **P-Factor** | 90% | 0.66 | 0.77 | 61% | 0.30 | 0.55 |
| **R-Factor** | 0.87 | 0.84 | 1.04 | 0.69 | 0.38 | 0.78 |

**Table 2. SUFI-2 simulation statistics for downstream (Longs).**

| | Calibration | | | Validation | | |
|---|---|---|---|---|---|---|
| | P-T | P-M | HG | P-T | P-M | HG |
| **NSE** | 0.77 | 0.63 | 0.69 | 0.90 | 0.83 | 0.80 |
| ***MSE*** | 325.70 | 635.95 | 551.99 | 140.02 | 251.47 | 286.75 |
| **P-Factor** | 75% | 0.57 | 0.69 | 52% | 0.32 | 0.49 |
| **R-Factor** | 0.79 | 0.80 | 0.93 | 0.72 | 0.38 | 0.80 |

P-T results can be categorized as "good" to "very good" in Moriasi et al's., (2007) qualitative rank while "satisfactory" to "good" for P-M and HG, respectively.

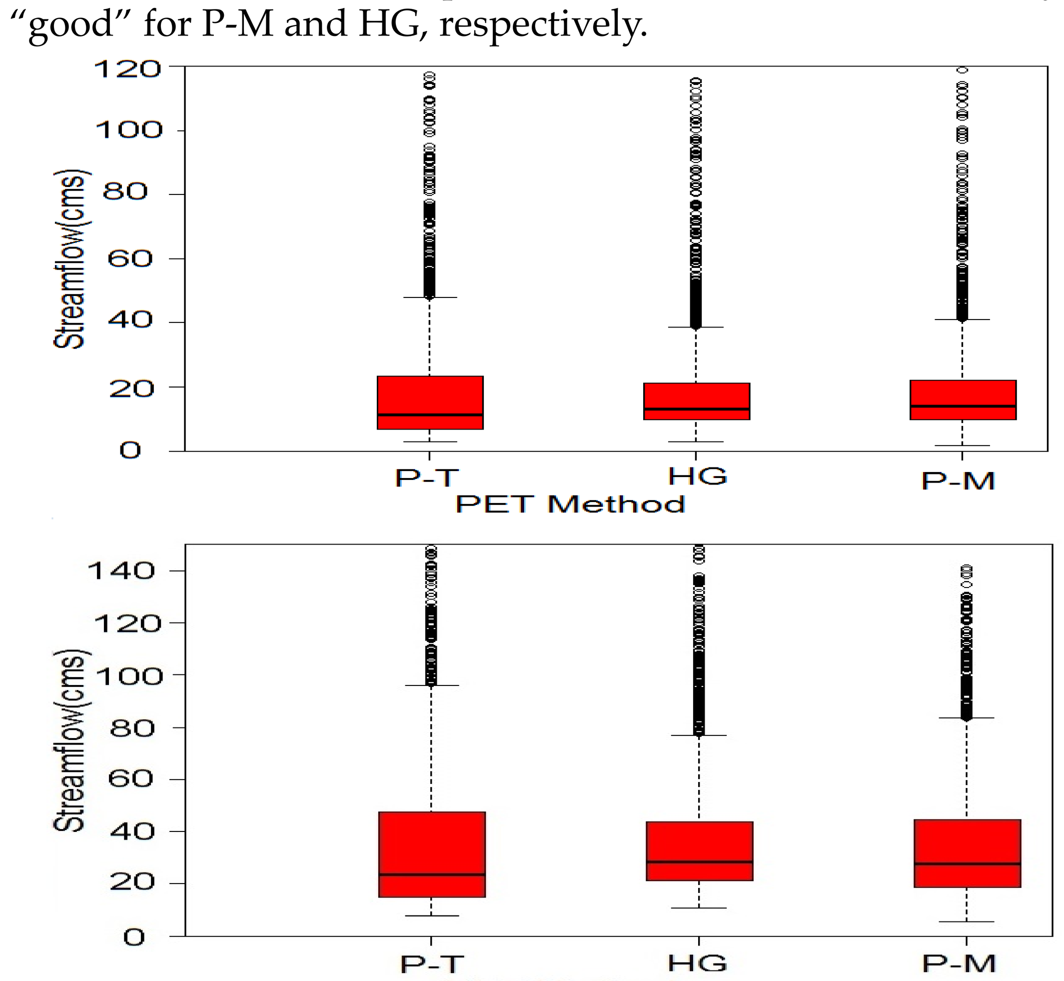


Figure 9. Box and whisker plots comparing different ET methods at the Freeland (top) and Longs (bottom) outlets.

## CONCLUSIONS

- SWAT results demonstrated that a radiation-based ET method (P-T method) performed significant results in forested wetland ecosystem with wet and humid surfaces.
- 21.2% of flow loss was consumed via stream evaporation and floodplains evapotranspiration, indicating that 78.8% of the loss within the entire study area represented land ET.
- Low flows (base flow) are sensitive to the changes in ET process in dry period but insensitive at the end of wet periods.

## ACKNOWLEDGEMENT

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